Search for contact interactions

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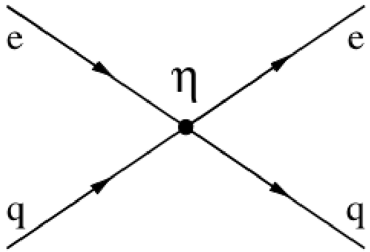
- LO calculation of CI effects
- Models of general CI
- Test of PDFs for LO calculations

Introduction to contact interactions

An investigation of possible effects due to the virtual exchange allows to search for evidance of new particles with mass much higher than center of mass energy.



Four-fermion *eeqq* contact interactions provide a convenient method for such search and can be represented by additional terms in the Standard Model Lagrangian:

$$\mathscr{L}_{CI} = \sum_{i,j=L,R;q=u,d} \eta_{ij}^{eq} (\bar{e}_i \gamma^{\mu} e_i)(\bar{q}_j \gamma_{\mu} q_j)$$

LO calculation of CI effects

For the LO NC cross sections calculation contact interactions can be added as an additional term in the tree level eq $\rightarrow$ eq scattering amplitude:

$$M_{ij}^{eq}(t) = -\frac{4\pi\alpha_{em} e_q}{t} + \frac{4\pi\alpha_{em}}{\sin^2\Theta_W \cdot \cos^2\Theta_W} \cdot \frac{g_i^e g_j^q}{t - M_Z^2} \boxed{+\eta_{ij}^{eq}}$$

And then the double-differential cross sections can be evaluated as usual:

$$\frac{d^2\sigma_{NC}^{e^- p}}{dxdQ^2} = \frac{1}{16\pi} \sum_q q(x,Q^2)\left\{(1-P)\left|M_{LL}^{eq}\right|^2 + (1+P)\left|M_{RR}^{eq}\right|^2 + (1-y)^2\left[(1-P)\left|M_{LR}^{eq}\right|^2 + (1+P)\left|M_{RL}^{eq}\right|^2\right]\right\} + \bar{q}(x,Q^2)\left\{(1-P)\left|M_{LR}^{eq}\right|^2 + (1+P)\left|M_{RL}^{eq}\right|^2 + (1-y)^2\left[(1-P)\left|M_{LL}^{eq}\right|^2 + (1+P)\left|M_{RR}^{eq}\right|^2\right]\right\}$$

$$\frac{d^2\sigma_{NC}^{e^+ p}}{dxdQ^2} = \frac{1}{16\pi} \sum_q q(x,Q^2)\left\{(1+P)\left|M_{LR}^{eq}\right|^2 + (1-P)\left|M_{RL}^{eq}\right|^2 + (1-y)^2\left[(1+P)\left|M_{LL}^{eq}\right|^2 + (1-P)\left|M_{RR}^{eq}\right|^2\right]\right\} + \bar{q}(x,Q^2)\left\{(1+P)\left|M_{LL}^{eq}\right|^2 + (1-P)\left|M_{RR}^{eq}\right|^2 + (1-y)^2\left[(1+P)\left|M_{LR}^{eq}\right|^2 + (1-P)\left|M_{RL}^{eq}\right|^2\right]\right\}$$

LO calculation of CI effects

For the LO CC cross sections calculation contact interactions terms η_{RL}^{eq} and η_{RR}^{eq} are absent since there are no right-handed neutrinos in the SM, and η_{LR}^{eq} were ruled out by pion decay data. Only differences

$$\eta_i^{e\nu ud} = \eta_{LL}^{ed_i} - \eta_{LL}^{eu_i}$$

change the Q^2 dependance of CC cross sections as:

$$\frac{d^2\sigma_{CC}^{e^- p}}{dxdQ^2} = (1-P)\frac{1}{\pi}\sum_{i=1}^{2}[u_i(x,Q^2)+(1-y)^2\bar{d}_i(x,Q^2)]\times[\frac{G_F}{\sqrt{2}}\frac{M_W^2}{M_W^2+Q^2}-\boxed{\frac{\eta_i^{e\nu ud}}{4}}]^2$$

$$\frac{d^2\sigma_{CC}^{e^+ p}}{dxdQ^2} = (1+P)\frac{1}{\pi}\sum_{i=1}^{2}[u_i(x,Q^2)+(1-y)^2\bar{d}_i(x,Q^2)]\times[\frac{G_F}{\sqrt{2}}\frac{M_W^2}{M_W^2+Q^2}-\boxed{\frac{\eta_i^{e\nu ud}}{4}}]^2$$

Models of general CI

Model	η_{LL}^{ed}	η_{LR}^{ed}	η_{RL}^{ed}	η_{RR}^{ed}	η_{LL}^{eu}	η_{LR}^{eu}	η_{RL}^{eu}	η_{RR}^{eu}
VV	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$
AA	$+\eta$	$-\eta$	$-\eta$	$+\eta$	$+\eta$	$-\eta$	$-\eta$	$+\eta$
VA	$+\eta$	$-\eta$	$+\eta$	$-\eta$	$+\eta$	$-\eta$	$+\eta$	$-\eta$
X1	$+\eta$	$-\eta$			$+\eta$	$-\eta$		
X2	$+\eta$		$+\eta$		$+\eta$		$+\eta$	
X3	$+\eta$			$+\eta$	$+\eta$			$+\eta$
X4		$+\eta$	$+\eta$			$+\eta$	$+\eta$	
X5		$+\eta$		$+\eta$		$+\eta$		$+\eta$
X6			$+\eta$	$-\eta$			$+\eta$	$-\eta$
U1					$+\eta$	$-\eta$		
U2					$+\eta$		$+\eta$	
U3					$+\eta$			$+\eta$
U4						$+\eta$	$+\eta$	
U5						$+\eta$		$+\eta$
U6							$+\eta$	$-\eta$

For the tests we work with VV model.

Test of PDFs for LO calculations

We implement CI effects on NLO cross sections as:

$$\sigma_{NLO+LO}^{SM+CI} = \sigma_{NLO}^{SM}(\boldsymbol{p}_1^{\boldsymbol{NLO}}) \times \left[\frac{\sigma_{LO}^{SM+CI}(\boldsymbol{p}_2^{\boldsymbol{LO}})}{\sigma_{LO}^{SM}(\boldsymbol{p}_2^{\boldsymbol{LO}})} \right]$$

where $\mathbf{p}_1$ and $\mathbf{p}_2$ are, in general, different sets of PDFs, evolved with DGLAP to NLO and LO correspondingly.

We have performed test on different choices of $\mathbf{p}_1$ and $\mathbf{p}_2$ by:

- calculating LO cross-section ratios as a function of Q^2;
- evaluating 95% CL upper limits on VV model with χ^2 method.

The ratios of LO SM+CI and SM cross sections:

$$\left[\frac{\sigma_{LO}^{SM+CI}\left(p_2^{LO}\right)}{\sigma_{LO}^{SM}\left(p_2^{LO}\right)}\right]$$

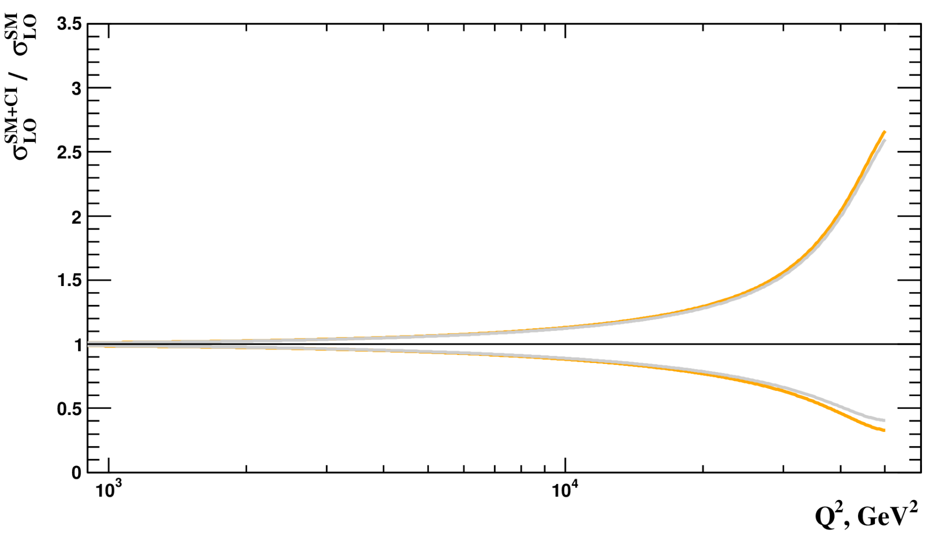
For VV model with two different variants of PDFs $\mathbf{p_2}$ fixed to SM:

$p_2^{LO} = p_{0\,SM}^{LO}$ (orange line)

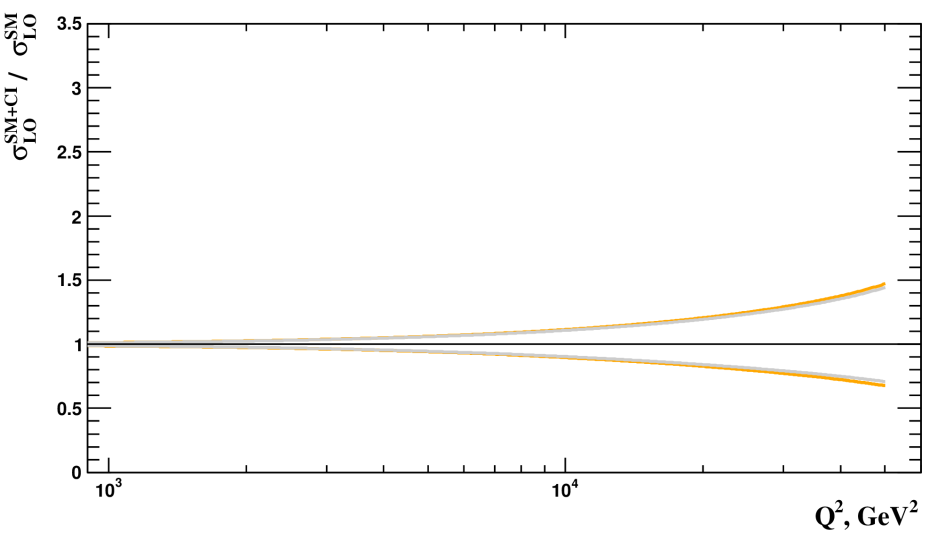
$p_2^{LO} = p_{0\,SM}^{NLO}$ (grey line)

With x = 0.5 and mass scales Λ^+ = 5 TeV and Λ^- = 5 TeV:

NC e^+p



NC e^-p



Cross-section ratios show low sensitivity to choice between LO and NLO PDFs.

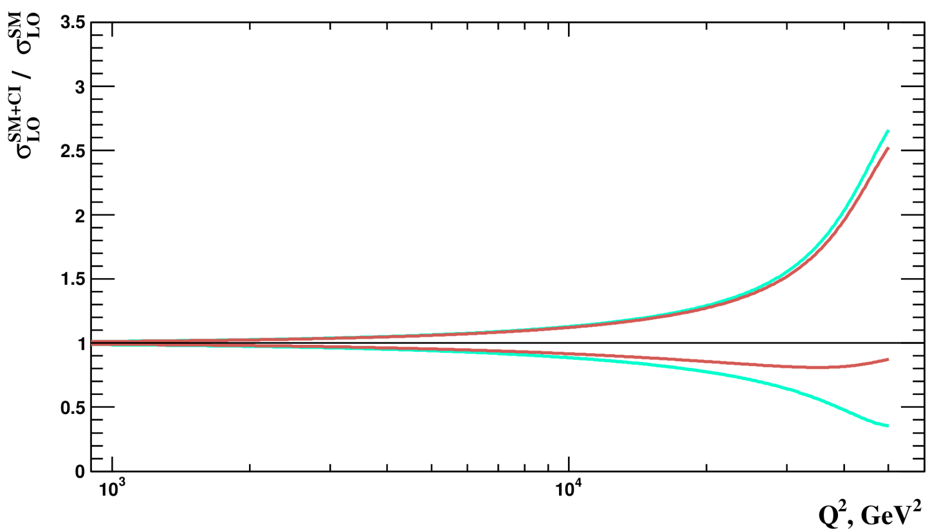
In case of PDFs $\mathbf{p_2}$ taken from LO and NLO fits including CI contribution:

$p_2^{LO} = p_1^{LO}$

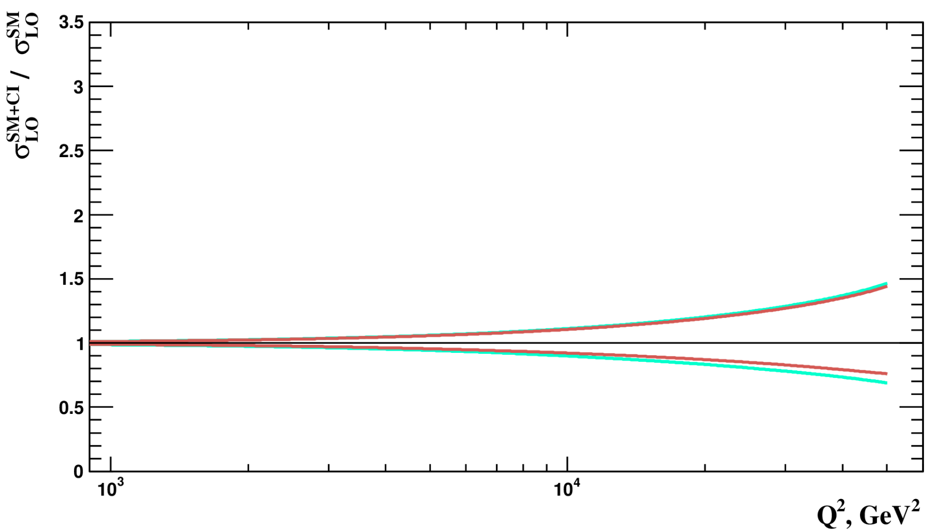
$p_2^{LO} = p_1^{NLO}$

For VV model with x = 0.5 and mass scales Λ^+ = 5 TeV and Λ^- = 5 TeV:

NC e^+p



NC e^-p

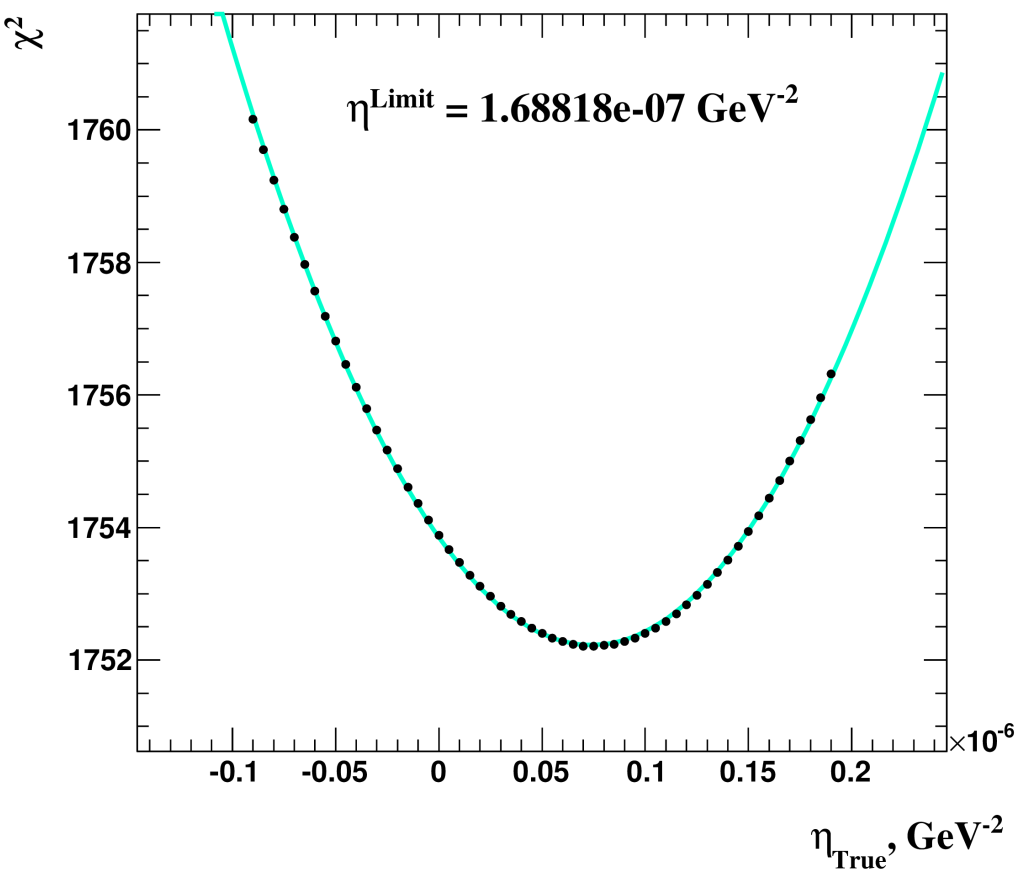


CI contribution affects LO and NLO QCD fits differently.

1) LO fit with:

$$p_2^{LO} = p_1^{LO}$$

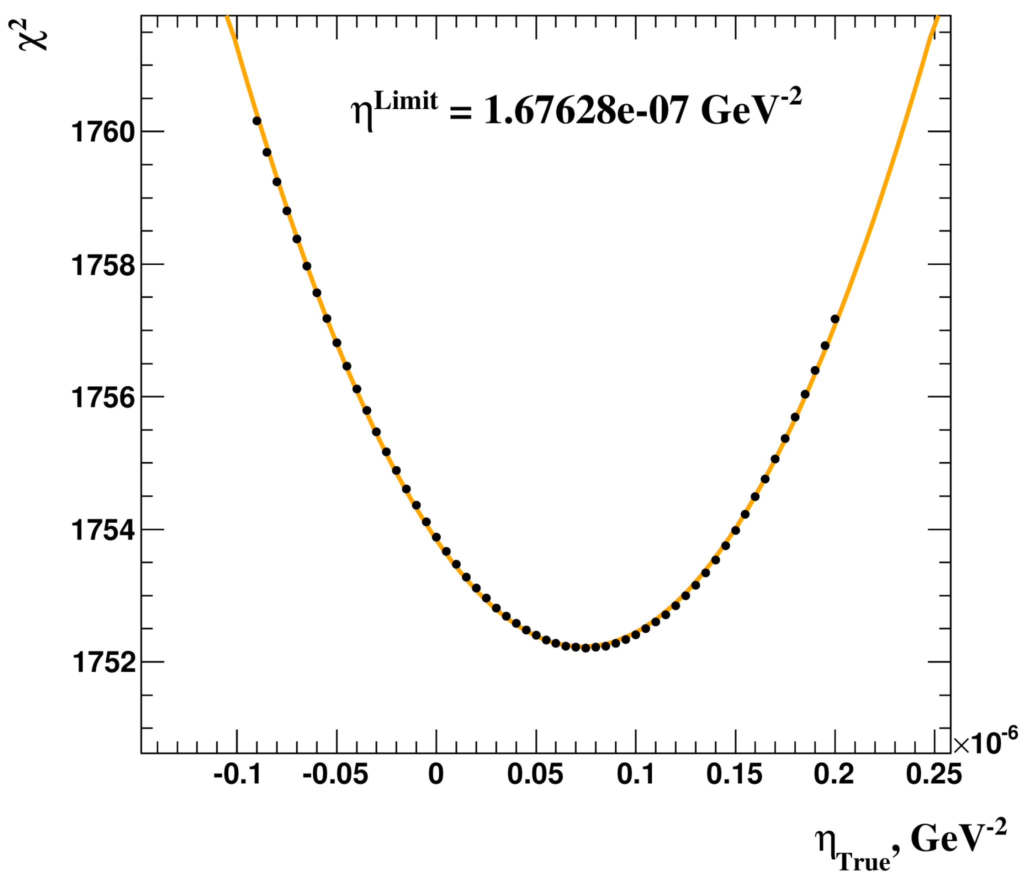
$$\sigma_{LO}^{SM+CI} = \sigma_{LO}^{SM}(p_1^{LO}) \times \left[\frac{\sigma_{LO}^{SM+CI}(p_1^{LO})}{\sigma_{LO}^{SM}(p_1^{LO})}\right]$$



2) LO fit with $\mathbf{p_2}$ fixed to SM fit results:

$$p_2^{LO} = p_{0\,SM}^{LO}$$

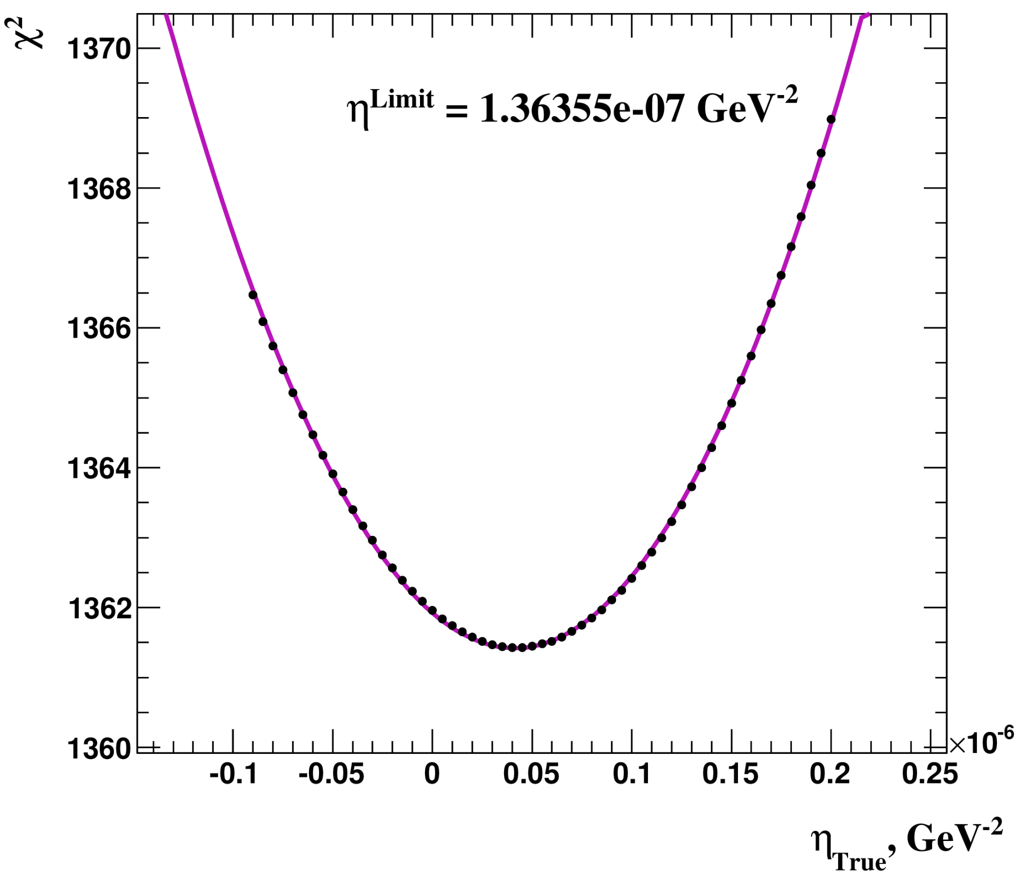
$$\sigma_{LO}^{SM+CI} = \sigma_{LO}^{SM}(p_1^{LO}) \times \left[\frac{\sigma_{LO}^{SM+CI}(p_{0\,SM}^{LO})}{\sigma_{LO}^{SM}(p_{0\,SM}^{LO})}\right]$$



3) NLO fit with $\mathbf{p_2}$ extracted in LO fit on Data for each value of η_i:

$$p_2^{LO} = p_{i\,SM+CI}^{LO}$$

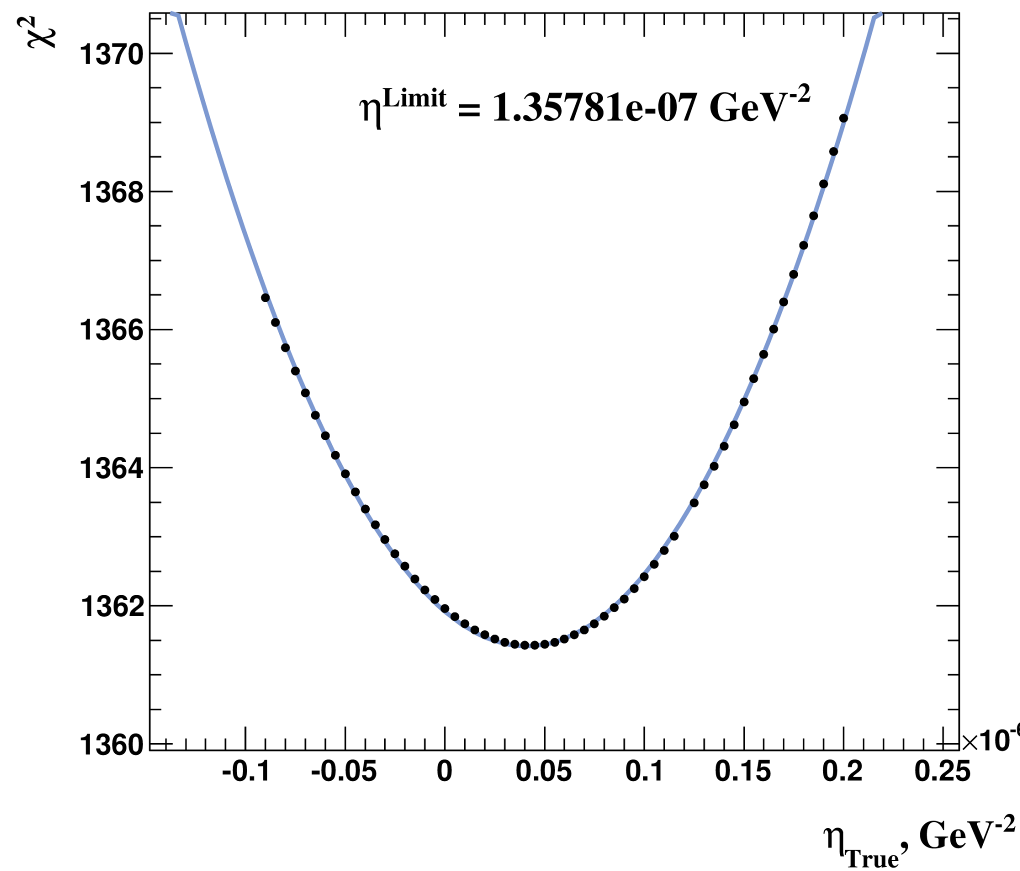
$$\sigma_{NLO+LO}^{SM+CI} = \sigma_{NLO}^{SM}(p_1^{NLO}) \times \left[\frac{\sigma_{LO}^{SM+CI}(p_{i\,SM+CI}^{LO})}{\sigma_{LO}^{SM}(p_{i\,SM+CI}^{LO})}\right]$$



4) NLO fit with $\mathbf{p_2}$ fixed to SM LO fit results:

$$p_2^{LO} = p_{0\,SM}^{LO}$$

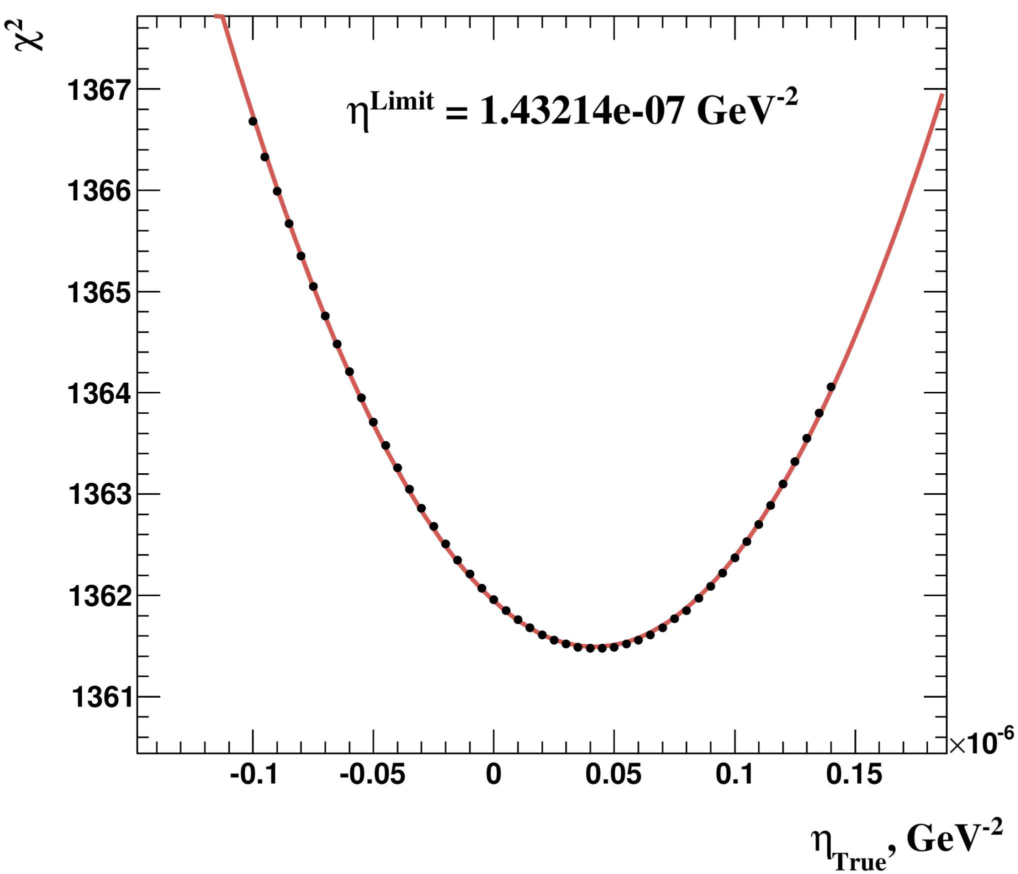
$$\sigma_{NLO+LO}^{SM+CI} = \sigma_{NLO}^{SM}(p_1^{NLO}) \times \left[\frac{\sigma_{LO}^{SM+CI}(p_{0\,SM}^{LO})}{\sigma_{LO}^{SM}(p_{0\,SM}^{LO})}\right]$$



5) NLO fit with:

$$p_2^{LO} = p_1^{NLO}$$

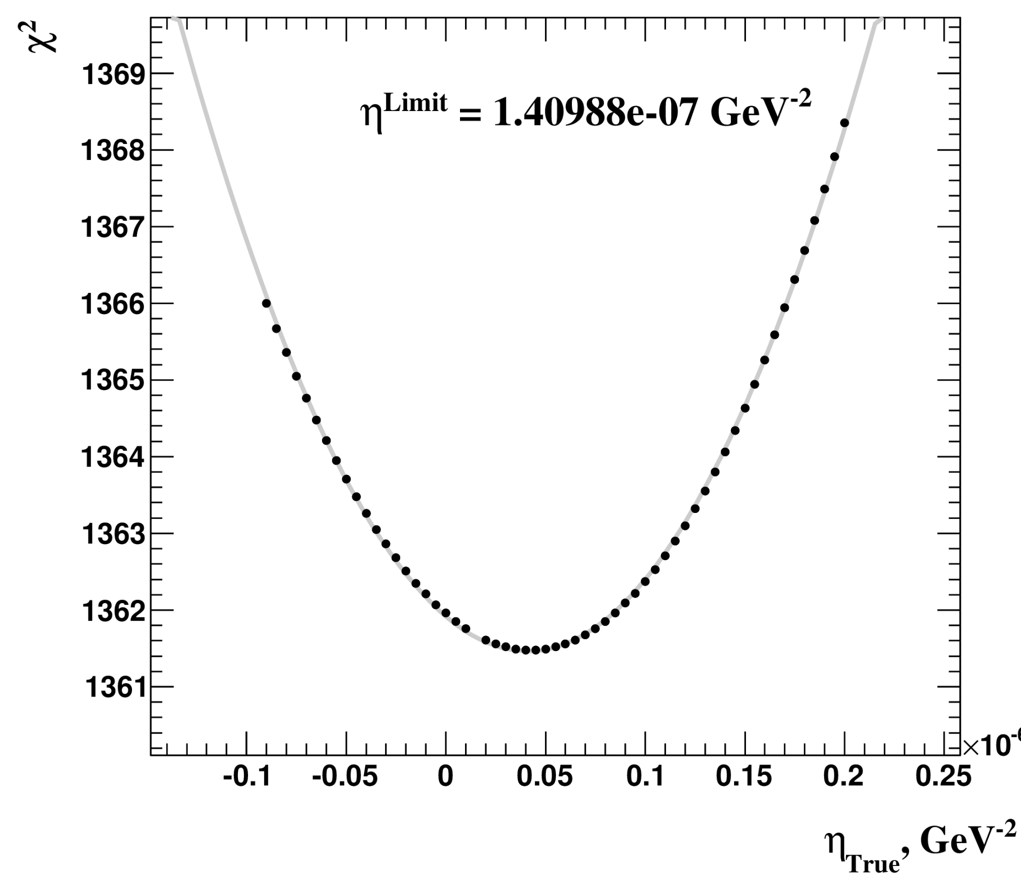
$$\sigma^{SM+CI}_{NLO+LO} = \sigma^{SM}_{NLO}\left(p_1^{NLO}\right) \times \left[\frac{\sigma^{SM+CI}_{LO}\left(p_1^{NLO}\right)}{\sigma^{SM}_{LO}\left(p_1^{NLO}\right)}\right]$$



6) NLO fit with p_2 fixed to SM NLO fit results:

$$p_2^{LO} = p_{0\,SM}^{NLO}$$

$$\sigma^{SM+CI}_{NLO+LO} = \sigma^{SM}_{NLO}\left(p_1^{NLO}\right) \times \left[\frac{\sigma^{SM+CI}_{LO}\left(p_{0\,SM}^{NLO}\right)}{\sigma^{SM}_{LO}\left(p_{0\,SM}^{NLO}\right)}\right]$$



Summary

- General contact interactions implemented into HERAFitter framework.
- Different PDFs for LO part of calculations tested on VV model.
- Cross-section ratio little sensitive to the choice between LO and NLO PDFs.
- Significant differences in CI influence on QCD fit result in LO and NLO.

→ We need to understand the difference better to select the best approach.